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Restoring & Monitoring on the Upper Mississippi River System

Long Term Resource Monitoring Program

Technical Report
2010–T001

Evaluation of Light Penetration on Navigation Pools 8 and 13 of the Upper Mississippi River

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Evaluation of Light Penetration on Navigation Pools 8 and 13 of the Upper Mississippi River

By Shawn Giblin, Kraig Hoff, Jim Fischer, and Terry Dukerschein

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Technical Report 2010–T001

U.S. Department of the Interior
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Preface

The Long Term Resource Monitoring Program (LTRMP) was authorized under the Water Resources Development Act of 1986 (Public Law 99–662) as an element of the U.S. Army Corps of Engineers' Environmental Management Program. The LTRMP is being implemented by the Upper Midwest Environmental Sciences Center, a U.S. Geological Survey science center, in cooperation with the five Upper Mississippi River System (UMRS) States of Illinois, Iowa, Minnesota, Missouri, and Wisconsin. The U.S. Army Corps of Engineers provides guidance and has overall Program responsibility. The mode of operation and respective roles of the agencies are outlined in a 1988 Memorandum of Agreement.

The UMRS encompasses the commercially navigable reaches of the Upper Mississippi River, as well as the Illinois River and navigable portions of the Kaskaskia, Black, St. Croix, and Minnesota Rivers. Congress has declared the UMRS to be both a nationally significant ecosystem and a nationally significant commercial navigation system. The mission of the LTRMP is to provide decision makers with information for maintaining the UMRS as a sustainable large river ecosystem given its multiuse character. The long-term goals of the Program are to understand the system, determine resource trends and effects, develop management alternatives, manage information, and develop useful products.

This report supports Task 2.2.3 as specified in Goal 2, Monitor Resource Change, of the LTRMP Operating Plan (U.S. Fish and Wildlife Service, 1993). This report was developed with funding provided by the LTRMP.

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Conversion Factors and Abbreviations

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)

Concentrations of chemical constituents in water are given in milligrams per liter (mg/L), and concentrations of turbidity are given in nephelometric turbidity units (NTU).

A nanometer (nm) is equal to 10^{-9} m (a billionth of a meter).

Abbreviations used in this report

LTRMP	Long Term Resource Monitoring Program
NTRU	nephelometric turbidity ratio units
NTU	nephelometric turbidity units
NVSS	nonvolatile suspended solids
PAR	photosynthetically active radiation
RM	river mile
R^2	coefficient of determination
SAV	submersed aquatic vegetation
TSS	total suspended solids
UMESC	Upper Midwest Environmental Sciences Center
UMRCC	Upper Mississippi River Conservation Committee
UMRS	Upper Mississippi River System
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
VSS	volatile suspended solids

Evaluation of Light Penetration on Navigation Pools 8 and 13 of the Upper Mississippi River

By Shawn Giblin, Kraig Hoff, Jim Fischer, and Terry Dukerschein

Abstract

The availability of light can have a dramatic affect on macrophyte and phytoplankton abundance in virtually all aquatic ecosystems. The Long Term Resource Monitoring Program and other monitoring programs often measure factors that affect light extinction (nonvolatile suspended solids, volatile suspended solids, and chlorophyll) and correlates of light extinction (turbidity and Secchi depth), but rarely do they directly measure light extinction. Data on light extinction, Secchi depth, transparency tube, turbidity, total suspended solids, and volatile suspended solids were collected during summer 2003 on Pools 8 and 13 of the Upper Mississippi River. Regressions were developed to predict light extinction based upon Secchi depth, transparency tube, turbidity, and total suspended solids. Transparency tube, Secchi depth, and turbidity all showed strong relations with light extinction and can effectively predict light extinction. Total suspended solids did not show as strong a relation to light extinction. Volatile suspended solids had a greater affect on light extinction than nonvolatile suspended solids. The data were compared to recommended criteria established for light extinction, Secchi depth, total suspended solids, and turbidity by the Upper Mississippi River Conservation Committee to sustain submersed aquatic vegetation in the Upper Mississippi River. During the study period, the average condition in Pool 8 met or exceeded all of the criteria whereas the average condition in Pool 13 failed to meet any of the criteria. This report provides river managers with an effective tool to predict light extinction based upon readily available data.

Background

Solar radiation affects the productivity and metabolism of aquatic ecosystems (Wetzel, 2001). A large portion of the biological energy production in lakes and rivers is a result of energy derived from solar radiation used in photosynthesis. The extinction of light in aquatic ecosystems is a function of the properties of water, particles suspended in the water, and dissolved and colored compounds in the water. In unproductive systems dissolved compounds play an important role in light extinction. Turbidity and phytoplankton abundance play a larger role in light extinction in more productive aquatic systems (Wetzel, 2001). Light extinction can exhibit considerable spatial and temporal variation within a given system. Weather, season, water quality, biological activity, ice cover, snow cover, flow regime, and vegetation density all can affect the amount of light available for photosynthetic activity.

The availability of light can have a dramatic affect on macrophyte and phytoplankton abundance and distribution in virtually all aquatic ecosystems. In turn, the abundance of macrophytes can affect the amount of nursery habitat for fish, invertebrate abundance, and water quality (Korschgen and others, 1997; Janecek, 1988). *Vallisneria americana* Michx. is considered an important resource for waterfowl and fish within the Upper Mississippi River System (UMRS) (Korschgen and others, 1997). Periodic declines of *Vallisneria* within the UMRS have had a negative effect on ecosystem health (Kimber and others, 1995). Light availability is a major factor affecting *Vallisneria* abundance, growth, and reproduction on the UMRS (Kimber and others, 1995; Doyle, 2000; Kreiling and others, 2007). Recent emphasis on the effect of light regime on submersed aquatic vegetation (SAV) in the UMRS has prompted researchers and river managers to relate commonly available light-penetration indicators (e.g., turbidity, Secchi depth, and total suspended solids (TSS)) to light extinction (Upper Mississippi River Conservation Committee, 2003).

The purpose of this study was threefold: (1) to develop relations between frequently measured water-quality parameters and light extinction, (2) to gage how tributary water quality affects light extinction in the UMRS, and (3) to determine what fraction of the suspended load, volatile versus nonvolatile, contributes more to light extinction in the river. Monitoring programs, including the Long Term Resource Monitoring Program (LTRMP), often measure factors that affect light extinction (nonvolatile suspended solids, volatile suspended solids, and chlorophyll) and other correlates of light extinction (turbidity and Secchi depth), but rarely do they directly measure light extinction. Developing relations between water-quality parameters and light extinction will provide river managers with additional tools to identify problems within the system.

Methods

In Pool 8 of the Upper Mississippi River, five transects consisting of three sites each were established on the main channel. The Black River, La Crosse River, Root River, and Coon Creek each were sampled at one location to monitor the tributaries to Pool 8. Transects were established at Minnesota Island (River Mile (RM) 701.1), Riverside Park immediately downstream of the La Crosse River (RM 698), immediately downstream of the Root River (RM 693.5), Horseshoe Island (RM 687.8), and immediately upstream of Lock and Dam 8 at Genoa, Wisconsin (RM 679.5, fig. 1). In Pool 13, four transects consisting of three to five sites each were established on main- and side-channel sites. The Maquoketa River, Apple River, Plum River, and Elk River each were sampled at one location to monitor the tributaries to Pool 13. The transect locations for Pool 13 were directly downstream of each tributary at RM 548.5, 545.1, 536.6, and 528.3 (fig. 2). All transects were perpendicular to the main channel. Transects were selected to measure the effect of tributaries and to detect whether lateral or longitudinal light gradients exist within the pools. Sites were sampled weekly from May 6 to July 16, 2003.

Data were collected at every site for turbidity, Secchi depth, transparency tube, and underwater photosynthetically active radiation (400 to 700 nm). Turbidity and Secchi depth information was obtained using standard LTRMP protocols (Soballe and Fischer, 2004). Turbidity was analyzed with a Hach 2100P turbidimeter (Hach Company, 1995) and reported in nephelometric turbidity units (NTU). The 2100P uses a tungsten-filament lamp light source, 90-degree detection angle, and multiple detectors with ratio compensation. The 2100P does not have the option of turning the ratio compensation off. With ratio compensation on, the instrument's microprocessor calculates a ratio of signals from each detector. For this reason, 2100P values are sometimes reported as nephelometric turbidity ratio units (NTRU). However, turbidity values are expressed as NTU for this report. The Hach 2100P was checked daily with low, medium, and high NTU Gelex Secondary Standards. The Hach 2100P turbidimeter was calibrated quarterly using Hach StablCal Stabilized Formazin Turbidity Standards.

The transparency tube was a clear, plastic tube 120 cm long marked in 1-cm increments with a small Secchi pattern painted on the bottom. Water was collected from 0.20 m below the surface and poured into the tube until the pattern disappeared. Readings were taken in the shade and recorded to the nearest centimeter (U.S. Environmental Protection Agency, 2006).

Samples for TSS and volatile suspended solids (VSS) were collected at one site per transect per sampling episode and at all tributaries according to LTRMP standard procedures (Soballe and Fischer, 2004). Suspended solids were determined gravimetrically following standard methods (Greenburg and others, 1992). TSS and VSS laboratory analysis was done at the U.S. Geological Survey Upper Midwest Environmental Sciences Center (UMESC) Water Quality Laboratory in La Crosse, Wisconsin. Nonvolatile suspended solid (NVSS) values were calculated by subtracting VSS from TSS.

Photosynthetically active radiation (PAR) was measured in micromoles s^{-1} m^{-2} using two LI-192SA Underwater Quantum Light Sensors and an LI-1000 datalogger (LI-COR, Inc., 2006). Calibration was done before and after sampling by holding the sensors side by side outdoors and recording three 10-second averages. A correction factor was applied to one cell to ensure both cells yielded the same response under identical light exposure. All underwater-light measurements were done between 1000 and 1500 hours. Both sensors were placed on a single pole and were positioned 90 degrees apart. The sensors were deployed over the side of the boat or from shore so that the upper sensor was approximately 0.25 m below the water surface and the lower sensor was 0.75 m below the water surface. The lower sensor was placed at 0.5 m in La Crosse River and Coon Creek when depth was insufficient. Sensors were held as close to horizontal as possible and placed to avoid shadows. The sensors were allowed to stabilize for 20 to 30 seconds and three 10-second readings were recorded for each site and later averaged. Light-extinction coefficient was calculated as

$$k = [\ln(Io) - \ln(Iz)]/z,$$

where

k	is light-extinction coefficient (1/m),
Io	is surface or upper light measurement,
Iz	is light measurement at depth z, and
z	is depth interval between Io and Iz.

The depth of 1 percent of surface light ($z_{11\%}$) was calculated as

$$(z_{11\%}) = \ln(100)/k.$$

Results and Discussion

Conditions During the Study Period

In 2003, discharge at Dam 8 was slightly above the recent average for May and July and slightly below average for June (table 1). Discharge at Dam 13 was slightly above average for May, below average for June, and near average for July (table 1). Based on LTRMP data for 1994–2002, main channel turbidity and TSS in 2003 were near average for Pool 8 and above average for Pool 13 (table 2). Substantial differences in water quality between Pools 8 and 13 (table 2) translated into differences in light-extinction measurements between the pools (table 3).

Figure 1. Navigation Pool 8 of the Upper Mississippi River. (Location of sampling sites for the light penetration study in red.)

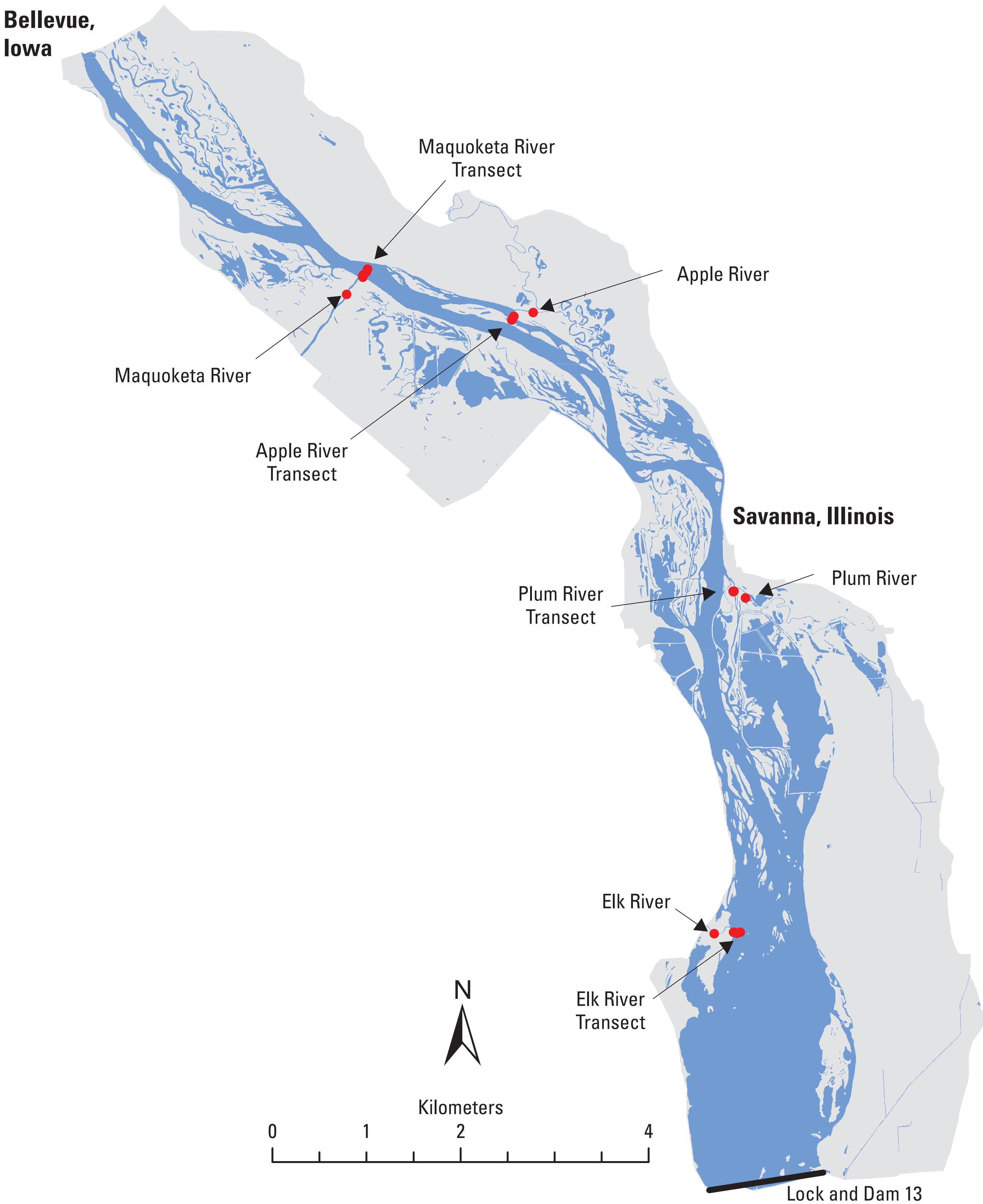

Figure 2. Navigation Pool 13 of the Upper Mississippi River. (Location of sampling sites for the light penetration study in red.)

Table 1. Average discharge for Dams 8 and 13 for 2003 compared to recent averages based on U.S. Army Corps of Engineers data.

[Data are reported in cubic feet per second]

Time period	Dam 8		Dam 13	
	1983–2002	2003	1986–2002	2003
May 6–May 31	64,922	81,392	89,732	109,986
June	52,603	46,743	75,614	60,828
July 1–July 16	55,273	62,650	76,098	76,366

Table 2. Average total suspended solids and turbidity for the study period compared to 1994–2002. The average for 1994–2002 is from Long Term Resource Monitoring Program sampling in the main channel during late July and early August of each year.

[TSS, total suspended solids; mg/L, milligrams per liter; NTU, nephelometric turbidity units]

Location and parameter	1994–2002 average	2003 study average
Pool 8 TSS (mg/L)	21.1	23.4
Pool 8 turbidity (NTU)	15.1	14.9
Pool 13 TSS (mg/L)	35.1	56.3
Pool 13 turbidity (NTU)	25.7	37.2

Table 3. Summary of average water-quality and light-extinction variables for 2003.

[cm, centimeter; NTU, nephelometric turbidity units; TSS, total suspended solids; mg/L, milligrams per liter; VSS, volatile suspended solids; m, meter]

Measurement	Pool 8	Pool 8 tributaries	Pool 13	Pool 13 tributaries
Secchi depth (cm)	64.10	57.79	36.44	40.67
Transparency tube (cm)	42.88	38.33	22.48	26.53
Turbidity (NTU)	14.89	22.83	37.22	27.11
TSS (mg/L)	23.42	49.75	56.26	32.13
VSS (mg/L)	5.82	8.74	11.41	7.31
Light extinction coefficient (m^{-1})	2.85	3.50	4.84	3.65
1 percent of surface light (m)	1.66	1.51	1.02	1.44

Historical Comparisons

Light-extinction data collected by the Wisconsin Department of Natural Resources at Lock and Dams 8 and 9 for 1988–98, that did not account for surface reflection, yielded an average light-extinction coefficient of 4.21 m^{-1} (J. Sullivan, unpub. data, 2007). Sullivan also collected data from Lock and Dams 8 and 9 during 2003–06 that yielded average light-extinction coefficients of 2.79 and 2.84 m^{-1}, respectively. An evaluation of light extinction in Pool 8 during 1983–84 yielded an average light-extinction coefficient of 4.08 m^{-1} (Korschgen and others, 1997). Another evaluation of light extinction (not accounting for surface reflection), conducted on Lake Onalaska in Pool 7 during the summer of 1990, showed an average light-extinction coefficient of 4.64 m^{-1} (Kimber and others, 1995). Examination of the data indicated increased light penetration in the UMRS in recent years. LTRMP data show that average concentrations of suspended solids in Pool 8 decreased appreciably during 1994–2002 (Johnson and Hagerty, 2008).

Comparisons of Water-Quality Parameters to Light Extinction

The small amount of light-extinction data available for the Upper Mississippi River have motivated researchers to develop regression models to predict light extinction based upon commonly collected water-quality parameters. In the majority of the regression analyses we conducted, nonlinear regression achieved higher R^2 values than linear regression. Data from Pool 8, Pool 13, and selected tributaries were combined to predict light extinction from TSS, transparency tube, turbidity, and Secchi depth (table 4). Data also were analyzed only from sites where all variables were measured to determine which of the four variables showed the highest proportion of variability in light extinction. Turbidity explained the highest proportion of variability among the four variables, whereas TSS explained the least proportion of variability (table 4). Data from Pools 8 and 13 also were segregated by pool and into tributary and main channel groups to compare regressions (table 5). These analyses revealed a greater correlation for the main channel sites than the tributary sites when data from both pools were combined.

Table 4. Regression between light-extinction coefficient (m^{-1}) (dependent variable) and water-quality parameters (independent variable). Data are combined for Pool 8 and tributaries and Pool 13 and tributaries.

[N, number of measurements; R^2, coefficient of determination; TSS, total suspended solids; mg/L, milligrams per liter; cm, centimeter; NTU, nephelometric turbidity units]

Independent variable	N	Equation	R^2
TSS (mg/L)	157	$y= 0.794x^{0.4241}$	0.676
Transparency tube (cm)	360	$y= 45.85x^{-0.7502}$	.823
Turbidity (NTU)	360	$y= 0.6973x^{0.5336}$	.822
Secchi depth (cm)	370	$y= 72.84x^{-0.7849}$	.788
Transparency tube (cm)[a]	157	$y= 42.95x^{-0.7375}$	.752
Turbidity (NTU)[a]	157	$y= 0.7152x^{0.5163}$	.769
Secchi depth (cm)[a]	157	$y= 63.44x^{-0.7557}$	.720

[a] Only sites with TSS data are included.

Table 5. Regression between light-extinction coefficient (m^{-1}) (dependent variable) and water-quality parameters (independent variable). Data are segregated for Pool 8 and Pool 13 tributary and main channel.

[R^2, coefficient of determination; TSS, total suspended solids; mg/L, milligrams per liter; cm, centimeter; NTU, nephelometric turbidity units]

Independent variable	Equation	R^2
Pool 8 and 13 tributaries TSS (mg/L)	$y= 0.9954x^{0.3524}$	0.564
Pool 8 and 13 main channel TSS (mg/L)	$y= 0.5149x^{0.5534}$	.879
Pool 8 with tributaries TSS (mg/L)	$y= 1.0444x^{0.3197}$	.620
Pool 13 with tributaries TSS (mg/L)	$y= 0.6023x^{0.5231}$	.786
Pool 8 main channel TSS (mg/L)	$y= 0.9512x^{0.3491}$	.629
Pool 13 main and side channel TSS (mg/L)	$y= 0.4402x^{0.5989}$	.804
Pool 8 and 13 tributaries transparency tube (cm)	$y= 43.811x^{-0.7567}$	.643
Pool 8 and 13 main channel transparency tube (cm)	$y= 46.157x^{-0.7471}$	.893
Pool 8 with tributaries transparency tube (cm)	$y= 49.425x^{-0.765}$	.701
Pool 13 with tributaries transparency tube (cm)	$y= 63.275x^{-0.8602}$	.758
Pool 8 main channel transparency tube (cm)	$y= 29.345x^{-0.6267}$	.515
Pool 13 main and side channel transparency tube (cm)	$y= 50.488x^{-0.7757}$	.846
Pool 8 and 13 tributaries turbidity (NTU)	$y= 0.762x^{0.4855}$	.653
Pool 8 and 13 main channel turbidity (NTU)	$y= 0.6821x^{0.5456}$	.888
Pool 8 with tributaries turbidity (NTU)	$y= 0.8085x^{0.4742}$	.674
Pool 13 with tributaries turbidity (NTU)	$y= 0.7096x^{0.5325}$	.765
Pool 8 main channel turbidity (NTU)	$y= 0.812x^{0.4713}$	.571
Pool 13 main and side channel turbidity (NTU)	$y= 0.8579x^{0.4862}$	.831
Pool 8 and 13 tributaries Secchi depth (cm)	$y= 55.799x^{-0.7358}$	.587
Pool 8 and 13 main channel Secchi depth (cm)	$y= 78.21x^{-0.7984}$	.867
Pool 8 with tributaries Secchi depth (cm)	$y= 117.49x^{-0.8985}$	.721
Pool 13 with tributaries Secchi depth (cm)	$y= 69.37x^{-0.7735}$	.653
Pool 8 main channel Secchi depth (cm)	$y= 64.626x^{-0.7561}$	.560
Pool 13 main and side channel Secchi depth (cm)	$y= 59.305x^{-0.7162}$	.750

Regressions also were developed relating light-extinction coefficient to TSS, transparency tube, turbidity, and Secchi depth data for each pool, including tributaries (table 5; figs. 3–6). The regressions for transparency tube, turbidity, and Secchi depth versus light extinction for Pools 8 and 13 were strong and similar during the study period. The regression for TSS versus light extinction, however, revealed substantial differences between Pools 8 and 13 when the tributaries were included. In addition, regressions were developed among all water-quality variables to estimate what the value of the dependent variable would be based on an independent variable value (e.g. estimated TSS based upon known turbidity; table 6). The regressions for TSS versus transparency tube and Secchi depth were weaker than the other regressions.

Comparison of various relations can reveal the value in predicting real-time environmental conditions within the river. Cole (1979) found that multiplying the Secchi depth by 2.7 to 3.0 provides a good estimate of the depth at which 1 percent of surface light penetrates (compensation point), delimiting the lower depth of the photic zone. A factor of 2.66 was derived using the data collected during this study (fig. 7). A similar relation was developed for transparency tube readings (fig. 8). In this case, a factor of 4.03 times the transparency tube reading provided an estimate of the compensation point. Nonlinear regression revealed an even stronger correlation for both of these relations. The equation for 1 percent of surface light versus Secchi depth is

$$(y = 2.3484x^{0.7849}, r^2 = 0.788).$$

The equation for 1 percent of surface light versus transparency tube is

$$(y = 3.1788x^{0.7502}, r^2 = 0.823).$$

Comparison of Results to Proposed Water-Quality Criteria

The Water Quality Section of the Upper Mississippi River Conservation Committee (UMRCC) has proposed water-quality criteria to sustain submersed aquatic vegetation in the UMRS (Upper Mississippi River Conservation Committee, 2003; table 7). During the study period the average condition in Pool 8 met all the criteria, whereas the average condition in Pool 13 failed to meet any of the criteria (table 7). Using regressions from table 4, the value at which each of the water-quality parameters met the UMRCC recommended light-extinction coefficient of 3.42 m^{-1} was 49.2 cm for Secchi depth, 31.3 milligrams per liter (mg/L) for TSS, 19.7 NTU for turbidity, and 31.8 cm for transparency tube. This indicates that the recommended TSS criteria of 25 mg/L may be too low, and a value nearer 30 mg/L may be more appropriate. The UMRCC light criteria did not include transparency tube data as a potential metric. Using regression data from table 4, a transparency tube measurement of roughly 32 cm corresponds to the recommended light-extinction coefficient of 3.42 m^{-1}.

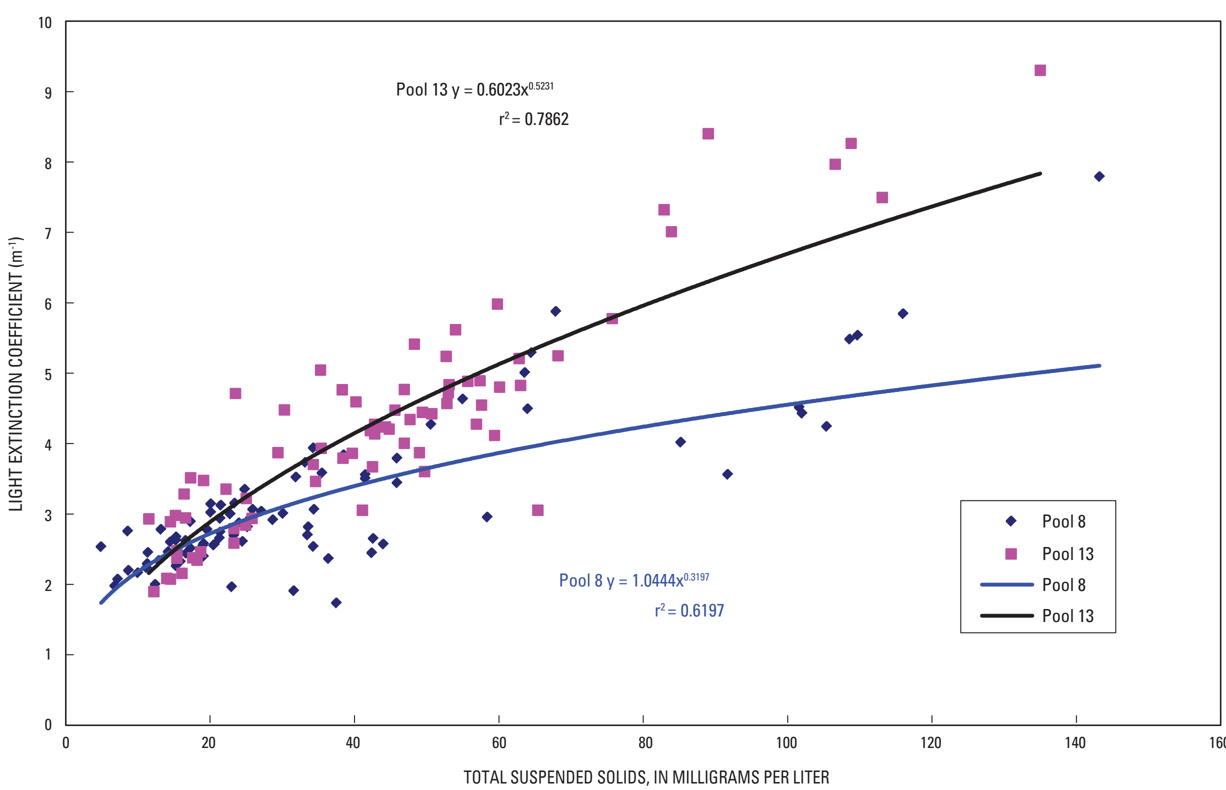

Figure 3. Relation between light-extinction coefficient and total suspended solids from Pools 8 and 13 (pool and tributary sites combined), Upper Mississipppi River, May 6 to July 16, 2003.

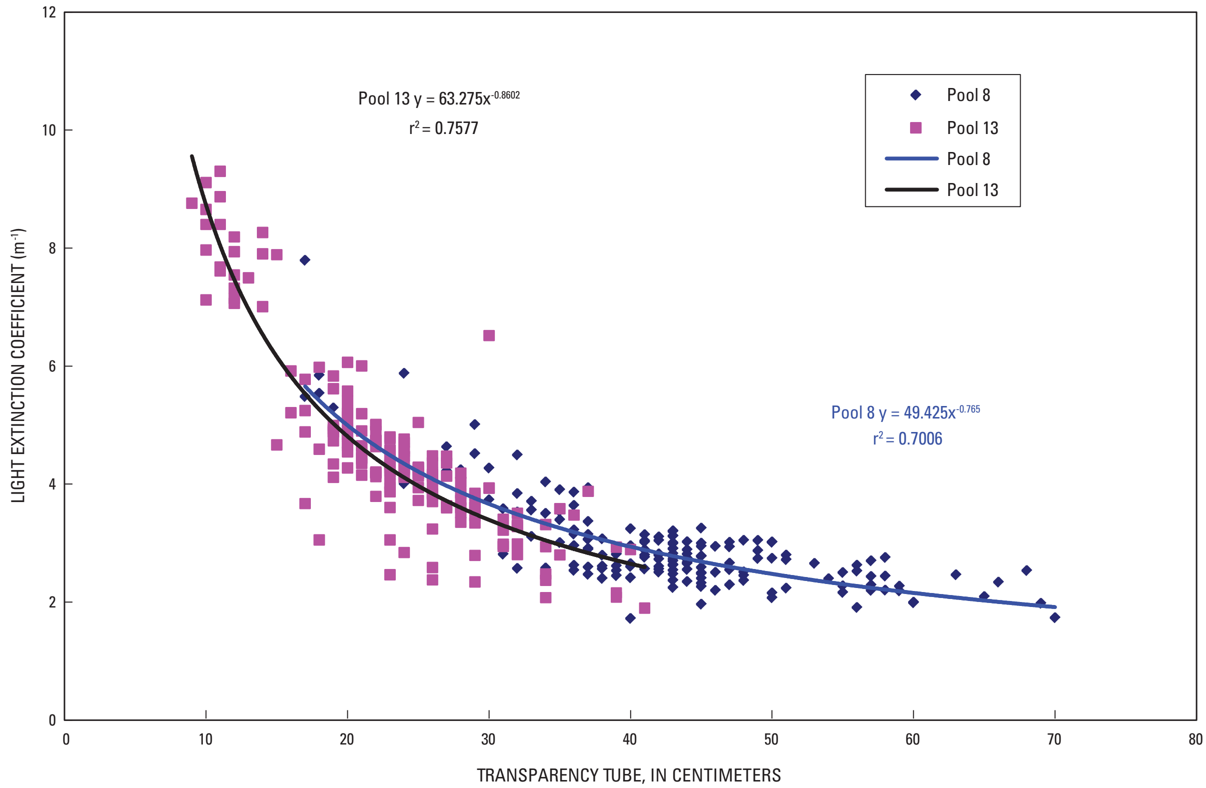

Figure 4. Relation between light-extinction coefficient and transparency tube from Pools 8 and 13 (pool and tributary sites combined), Upper Mississipppi River, May 6 to July 16, 2003.

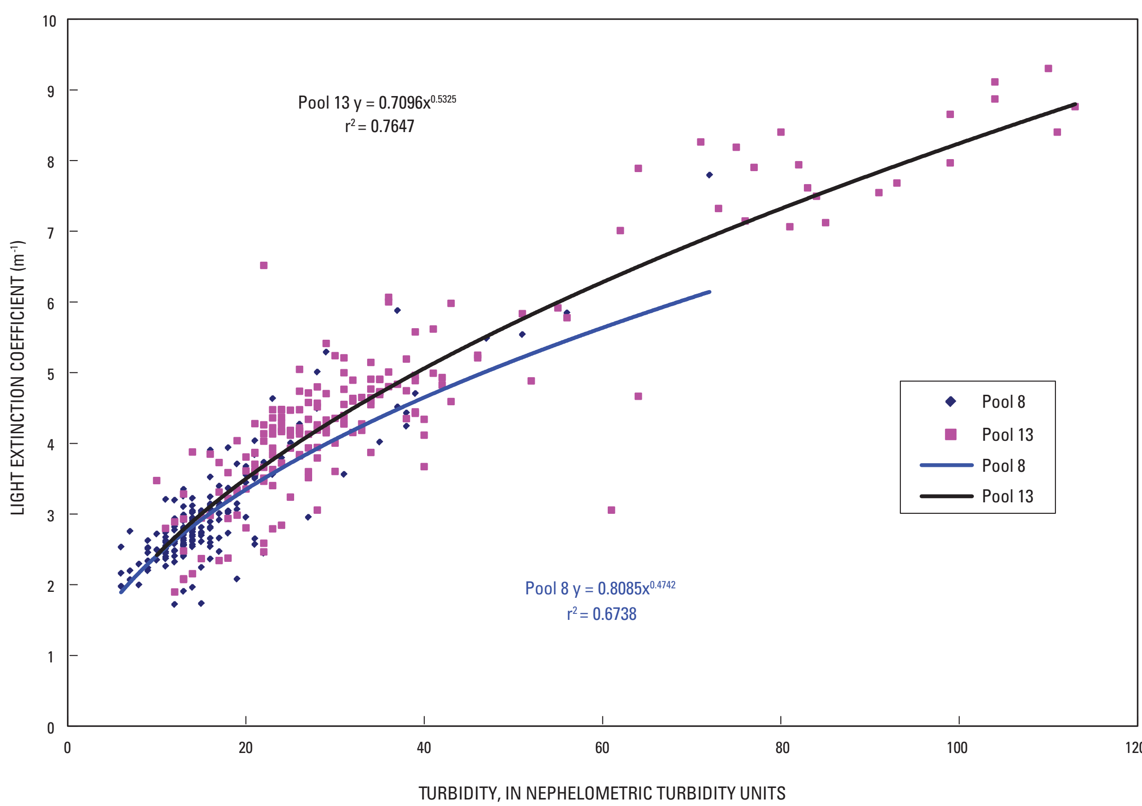

Figure 5. Relation between light-extinction coefficient and turbidity from Pools 8 and 13 (pool and tributary sites combined), Upper Mississipppi River, May 6 to July 16, 2003.

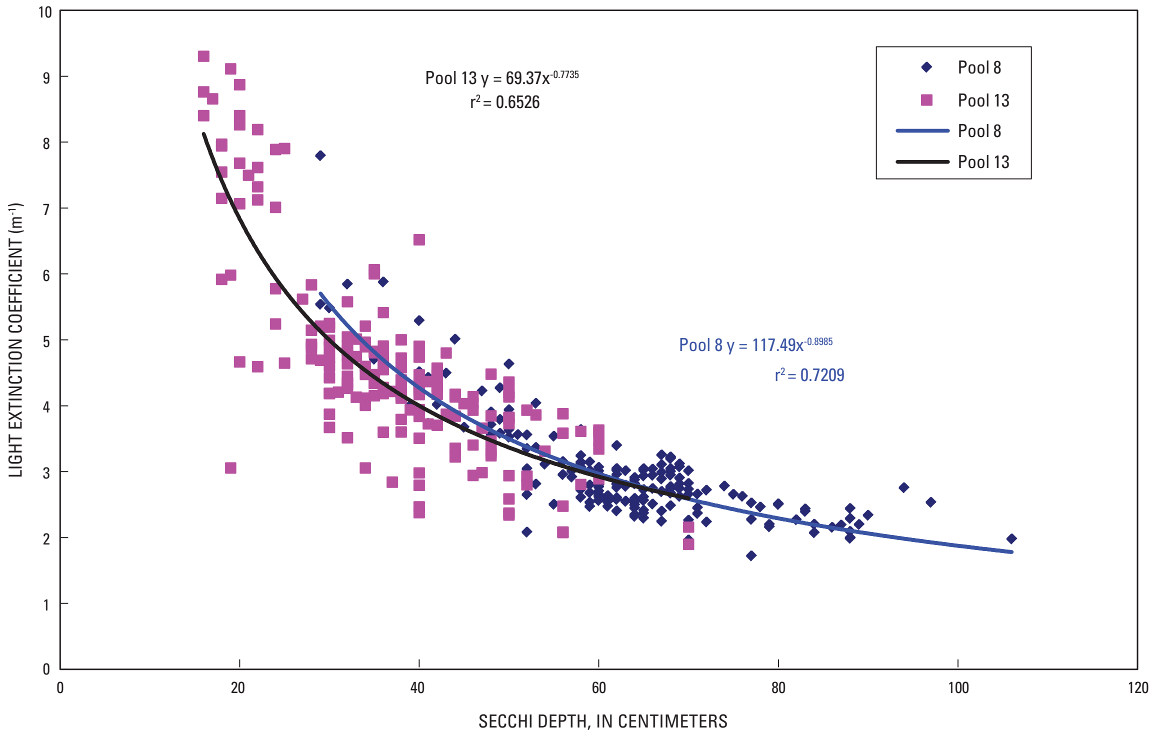

Figure 6. Relation between light-extinction coefficient and Secchi depth from Pools 8 and 13 (pool and tributary sites combined), Upper Mississipppi River, May 6 to July 16, 2003.

Table 6. Relation between water-quality parameters for 2003 study using data combined from Pool 8, Pool 13, and tributaries.

[R^2, coefficient of determination; N, number of measurements; cm, centimeter; TSS, total suspended solids; mg/L, milligrams per liter; NTU, nephelometric turbidity units]

Independent variable	Dependent variable	Equation	R^2	N
Transparency tube (cm)	Secchi depth (cm)	$y= 1.3361x+6.6764$	0.898	360
Transparency tube (cm)	TSS (mg/L)	$y= 2627x^{-1.29}$	.613	157
Transparency tube (cm)	Turbidity (NTU)	$y= 2073.5x^{-1.3458}$	.894	360
Secchi depth (cm)	Transparency tube (cm)	$y= 0.6722x-1.1867$	.898	360
Secchi depth (cm)	TSS (mg/L)	$y= 5179.1x^{-1.3225}$	.575	157
Secchi depth (cm)	Turbidity (NTU)	$y= 4900.4x^{-1.4149}$	.876	360
TSS (mg/L)	Transparency tube (cm)	$y= 158.32x^{-0.4749}$	.613	157
TSS (mg/L)	Secchi depth (cm)	$y= 211.54x^{-0.4344}$	.575	157
TSS (mg/L)	Turbidity (NTU)	$y= 1.3159x^{0.8006}$	.834	157
Turbidity (NTU)	Transparency tube (cm)	$y= 228.69x^{-0.6646}$	.894	360
Turbidity (NTU)	Secchi depth (cm)	$y= 309.84x^{-0.6193}$	.876	360
Turbidity (NTU)	TSS (mg/L)	$y= 1.332x^{1.0421}$	.834	157

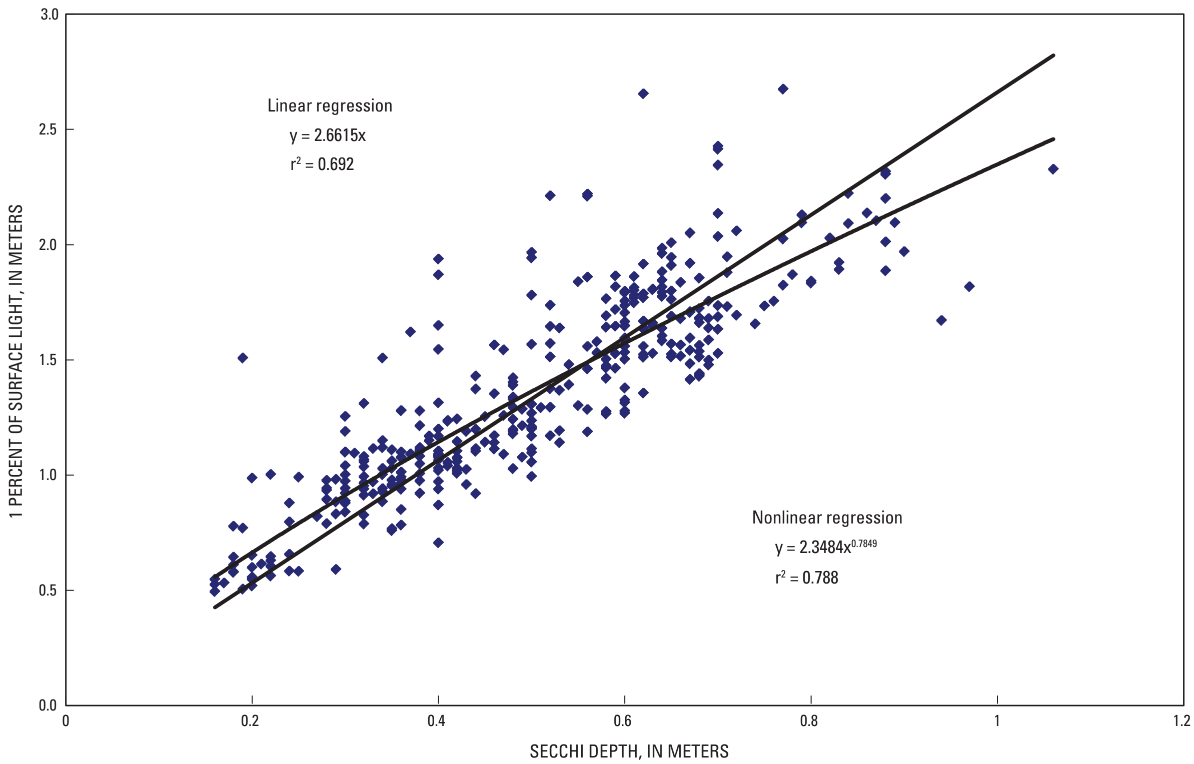

Figure 7. Relation between 1 percent of surface light and Secchi depth from Pools 8 and 13 (pool and tributary sites combined), Upper Mississipppi River, May 6 to July 16, 2003.

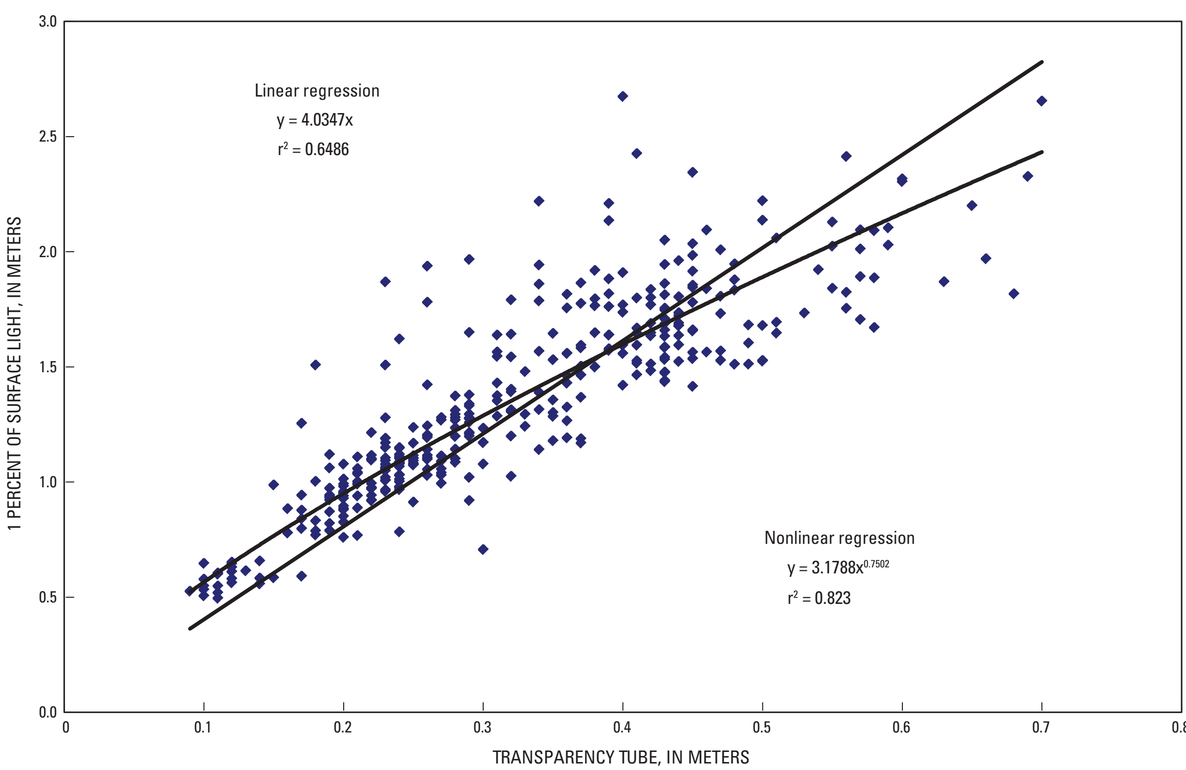

Figure 8. Relation between 1 percent of surface light and transparency tube from Pools 8 and 13 (pool and tributary sites combined), Upper Mississipppi River, May 6 to July 16, 2003.

Table 7. Comparison of Upper Mississippi River Conservation Committee recommended water-quality criteria (UMRCC, 2003) to main channel data from Pools 8 and 13 for May 6 to July 16, 2003.

[cm, centimeter; TSS, total suspended solids; mg/L, milligrams per liter; NTU, nephelometric turbidity units; ≤, less than or equal to; ≥, greater than or equal to]

	Light extinction coefficient (m^{-1})	Secchi depth (cm)	TSS (mg/L)	Turbidity (NTU)
UMRCC recommendation	≤ 3.42	≥ 50	≤ 25	≤ 20
Pool 8—main channel average	2.85	64.1	23.4	14.9
Pool 13—main channel average	4.84	36.4	56.3	37.2

Effects of Tributaries on Light Extinction

Water quality within the Upper Mississippi River is dependent upon the water quality of the tributaries feeding the system (Wasley, 2000). The degree that water quality is affected is a function of the discharge and concentration of suspended sediment of the tributary relative to the UMRS. The LTRMP monitored water quality in the tributaries of Pools 8 and 13, including data on TSS, turbidity, and Secchi depth. Based on this study, the average light-extinction coefficient of the tributaries to Pool 8 was higher than the Pool 8 main channel, whereas the average light-extinction coefficient of the tributaries to Pool 13 was lower than the Pool 13 main channel. Within Pool 8, the Black River had a lower light-extinction coefficient, and the La Crosse River, Root River, and Coon Creek had a higher light-extinction coefficient than the main channel (fig. 9). Scheffe's multiple-comparison procedure (Zar, 1984) indicated that light extinction in the main channel was significantly different than the La Crosse River and Coon Creek at the 0.05 level during the study period. Within Pool 13, the Elk, Apple, and Plum Rivers had lower light-extinction coefficients, and the Maquoketa River had a higher light-extinction coefficient than the main channel (fig. 10). Scheffe's multiple-comparison procedure indicated that light extinction in the main channel was significantly different than the Apple and Elk Rivers at the 0.05 level during the study period.

Tributaries can affect water quality laterally across the Mississippi River (Houser, 2005). Data collected during this study showed an east to west gradient of light penetration in Pool 8 with light penetration being slightly deeper on the east side of the main channel (fig. 11). The data point for the Root River Transect, Site 1, is suspect owing to two light-penetration observations that were extremely low for observed TSS, turbidity, and transparency tube values from the same site visit. The east to west gradient can be partially explained by the incomplete mixing of water from the Black River. Analysis of LTRMP fixed-site sampling data for 2000–05 (during the same months as the study period) indicated that a high proportion of NVSS settled out upstream in Lake Onalaska as the Black River traveled through the lake from Pool 7 into Pool 8 (fig. 1). The concentration of VSS also declined (at a slower rate) and remained lower downstream of Lake Onalaska than that found in the main channel in Pool 8 (table 8). The loss of NVSS at a faster rate than VSS likely was the result of faster sinking rates of NVSS, which is consistent with observations at Lake Pepin (Megard, 2006a). Although the La Crosse River had a high light-extinction coefficient, the Black River discharge was many times greater than the La Crosse River, resulting in lower light extinction on the east side of the Mississippi River downstream of the La Crosse and Black Rivers (table 9). Turbidity generally was higher in the west side of the river relative to the east side with the Root River and Genoa Transects showing the most pronounced gradient (fig. 12). In Pool 13, lateral gradients in turbidity were less pronounced. The only pattern was an increase in main channel turbidity on the west side of the main channel where the turbid Maquoketa River empties into the Upper Mississippi River. The lack of pattern likely was the result of the relatively small flow contribution of three of the four tributaries entering Pool 13 relative to the Upper Mississippi River (table 9).

A weak longitudinal light-penetration gradient was observed for Pool 8 with an increase in light-extinction coefficient downstream. Although this trend was statistically insignificant, the lack of significance likely can be attributed to small sample size. High light-extinction values of the tributaries discharging to lower Pool 8 and wave-induced sediment resuspension owing to long wind fetch likely contributed to this trend. The poorest area for light penetration in Pool 8 (west side of the Genoa Transect) is scheduled for rehabilitation to reduce sediment resuspension. Data collected during this study indicate that management efforts are being directed effectively to an area in the pool with high concentrations of suspended sediment.

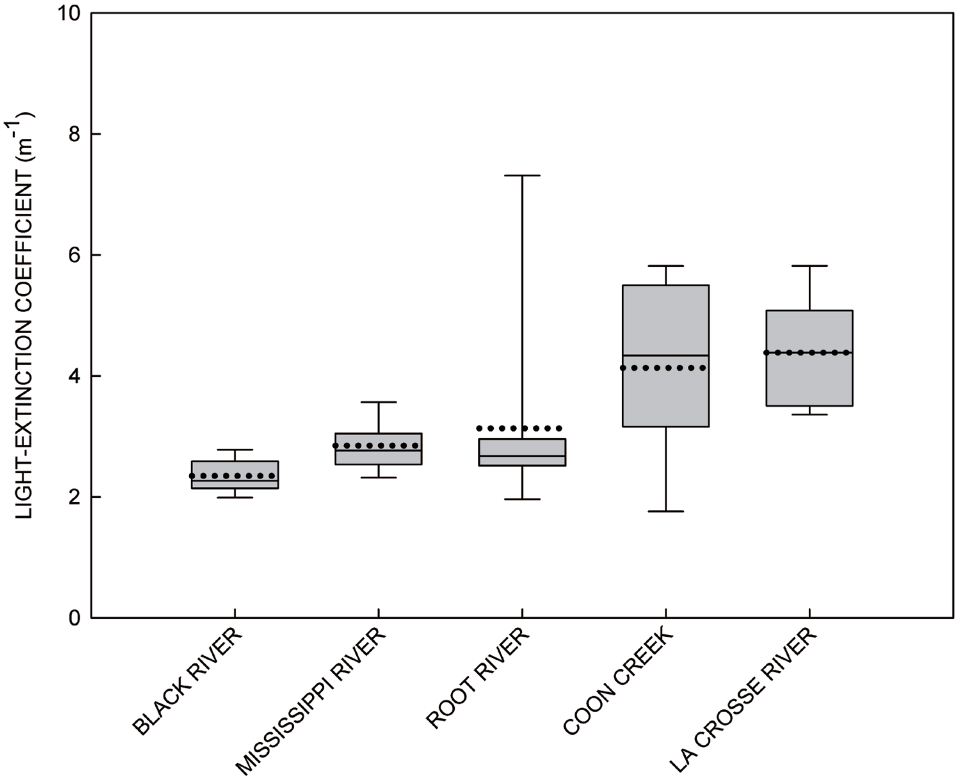

Figure 9. Pool 8 light-extinction summary. The solid line inside the box is the median. The upper and lower ends of the box are the 25th and 75th percentiles. The whiskers denote the 10th and 90th percentiles. The dotted line is the average for each site.

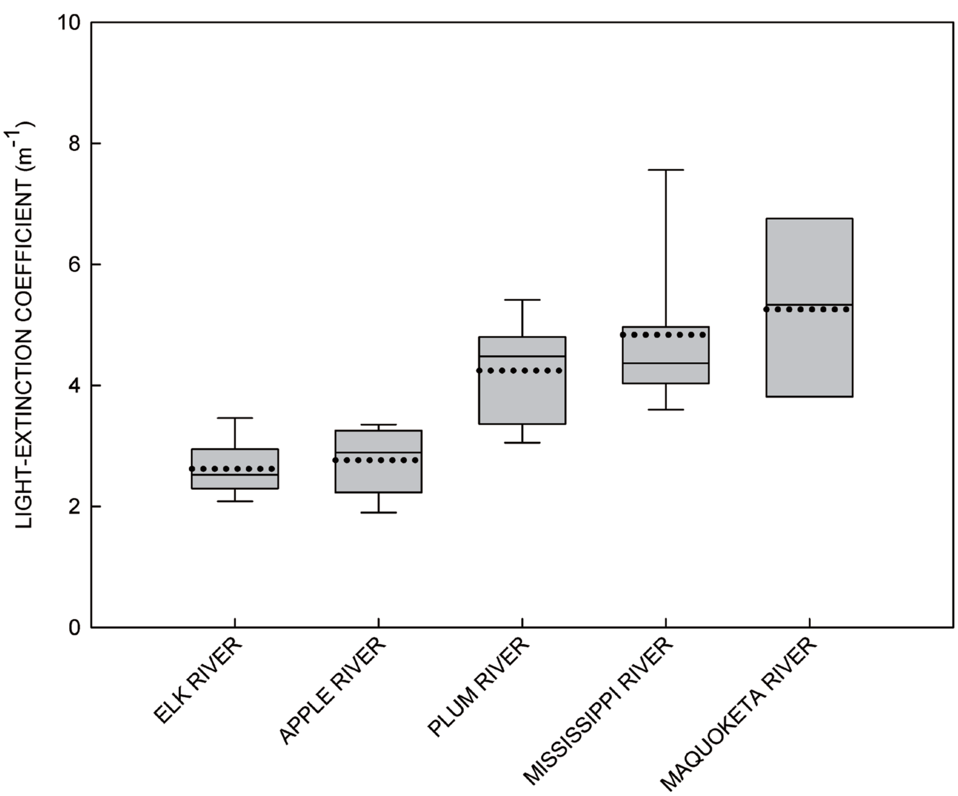

Figure 10. Pool 13 light-extinction summary. The solid line inside the box is the median. The upper and lower ends of the box are the 25th and 75th percentiles. The whiskers denote the 10th and 90th percentiles. The dotted line is the average for each site.

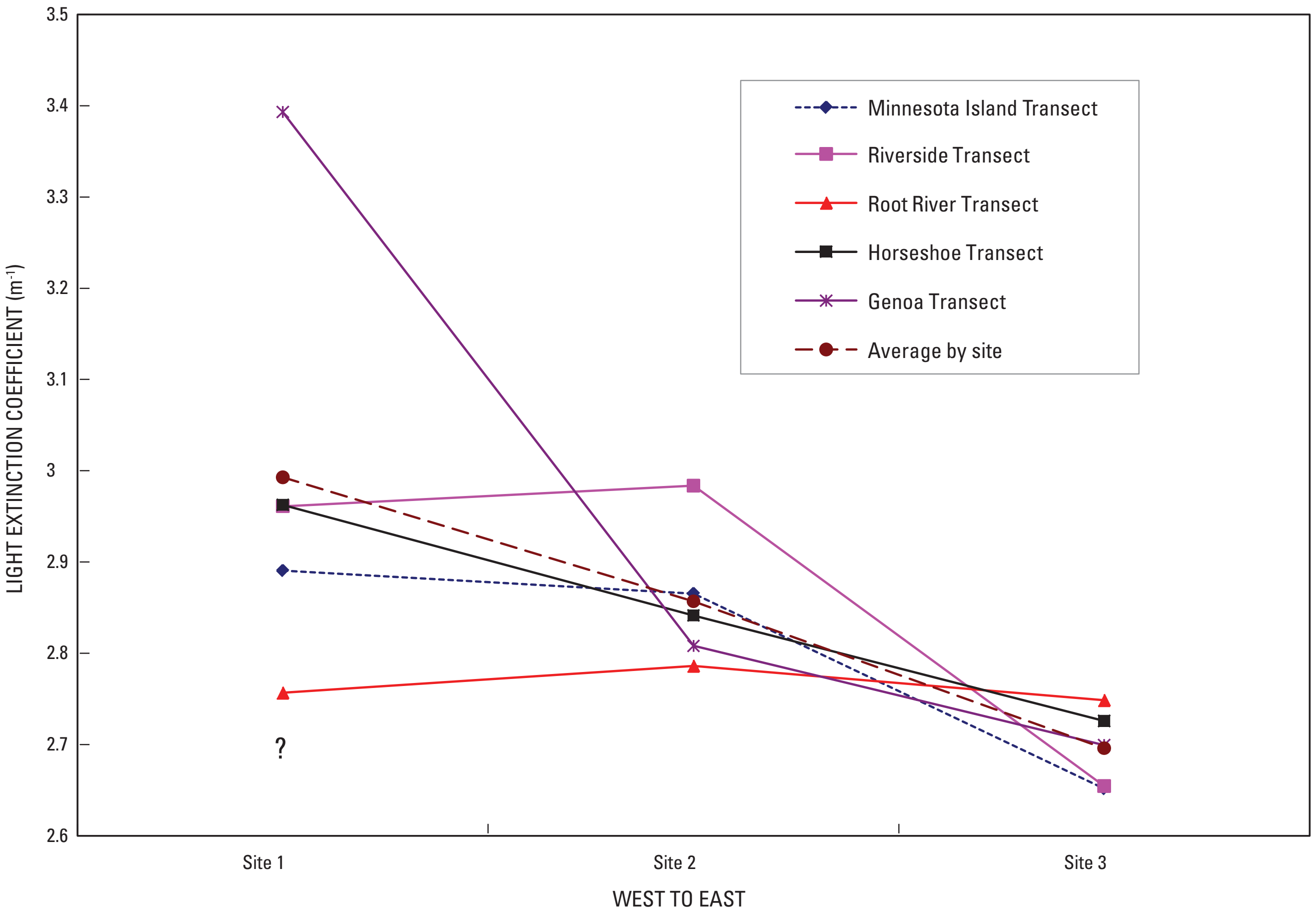

Figure 11. Mississippi River Pool 8 average light-extinction coefficient by transect. The question mark indicates this data point is suspect.

Table 8. Comparison of average water-quality characteristics of the Black River upstream and downstream of Lake Onalaska compared to the main channel of the Mississippi River in Pool 8. Data are from May 6 to July 16 from 2000 to 2005.

[NTU, nephelometric turbidity units; TSS, total suspended solids; mg/L, milligrams per liter; VSS, volatile suspended solids]

	Turbidity (NTU)	TSS (mg/L)	VSS (mg/L)
Black River upstream of Lake Onalaska (BK 14.2M)	16.4	23.1	5.9
Black River downstream of Lake Onalaska (BK 01.0M)	6.1	7.4	4.4
Mississippi River in upper Pool 8 (M 701.1D)	16.8	23.9	5.8

Table 9. Average discharge for the Mississippi River and tributaries for 1970–2000 based on U.S. Geological Survey data.

[UMR, Upper Mississippi River; data are in cubic feet per second]

River	Discharge	River	Discharge
Black River[a]	2,111	Maquoketa River[a]	1,259
La Crosse River[a]	469	Apple River[a]	217
Root River[a]	1,047	Plum River[a]	235
Coon Creek[a]	60	Elk River[c]	42
UMR at Winona, Minnesota (Pool 6)[b]	34,290	UMR at Clinton, Iowa (Pool 14)[b]	54,000

[a] Data from Wasley (2000).

[b] U.S. Geological Survey (USGS) gaging station data for 1970–2000.

[c] USGS gaging station data for 1995–97.

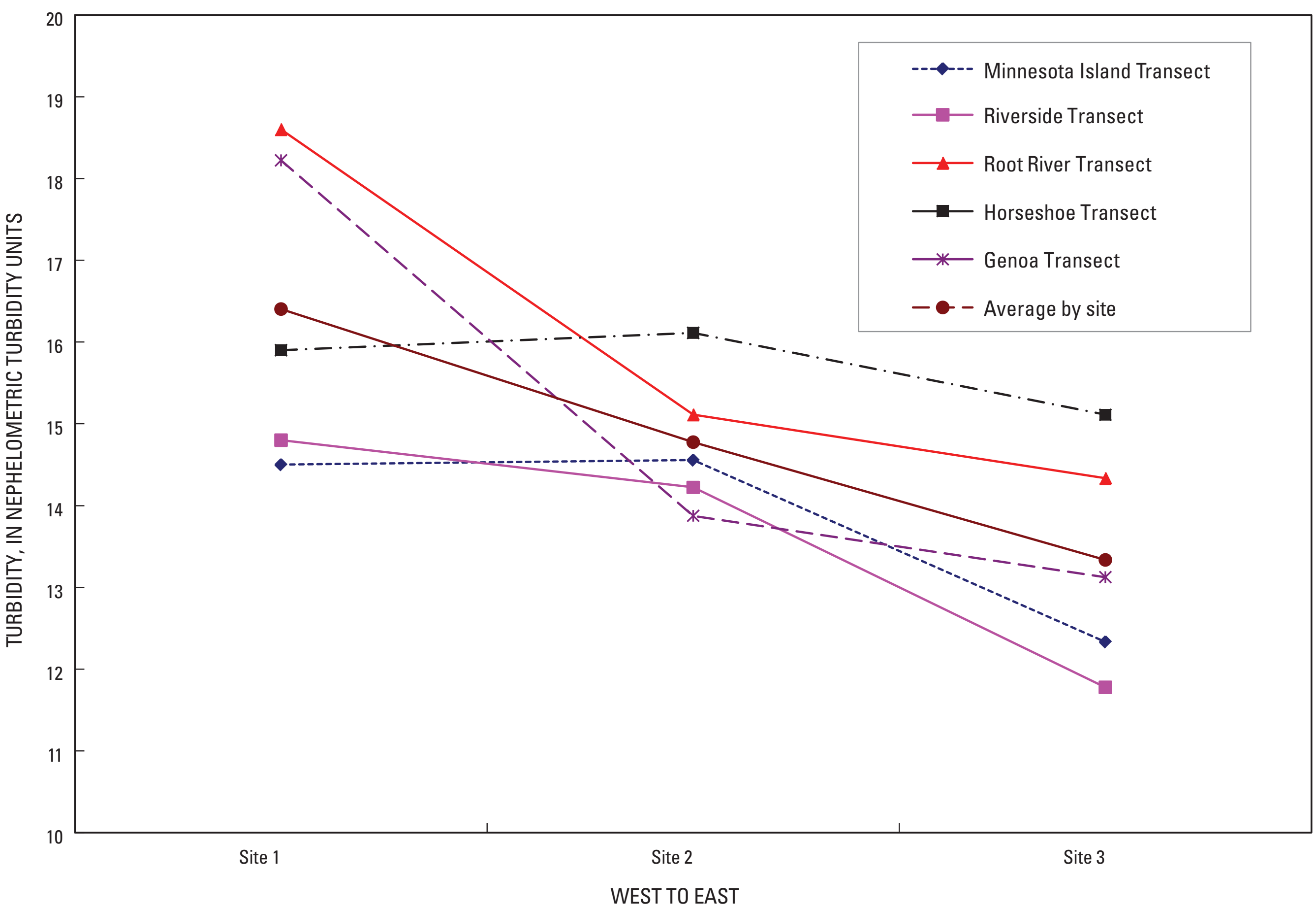

Figure 12. Mississippi River Pool 8 average turbidity by transect.

Effects of Composition of Suspended Solids on Light Extinction

The light-scattering properties of suspensoids in lentic systems tend to vary depending upon the proportion of organic (VSS) and inorganic (NVSS) particles in suspension (Megard, 2006a). Generally, organic suspensoids scatter light more strongly than inorganic suspensoids (Megard, 2006b). Multiple linear regression of data collected during this study resulted in the following equation:

$$\text{Light-Extinction Coefficient } (m^{-1}) = 1.0961 + 0.2497 \text{ (VSS mg/L)} + 0.0167 \text{ (NVSS mg/L)}$$
$$R^2 = 0.808.$$

This equation supports the theory that VSS is a greater light attenuator proportionally than NVSS; however, NVSS tends to occur at higher concentrations in the UMRS. The average concentration of VSS was 8.2 mg/L, and the average concentration of NVSS was 31.5 mg/L during the study period. Based on the regression equation above, on average, the concentration of VSS accounts for 56 percent of light extinction and NVSS accounts for 14 percent. The intercept estimates background extinction owing to unmeasured variables, including dissolved organic carbon, which on average accounts for 30 percent of light extinction.

The different effects of the contribution of NVSS and VSS to light extinction may illustrate the differences between Pools 8 and 13 in the relation of TSS to light extinction (fig. 3). During the study period, Pool 13 had a higher average concentration of VSS (a greater light attenuator) and therefore, a higher light-extinction coefficient. This response was more pronounced at higher concentrations of TSS and may account for some of the disparity between Pools 8 and 13 at concentrations of TSS exceeding 80 mg/L (table 10). It also is likely that variability in the proportion of TSS that is comprised of VSS is a cause for the weak relation between TSS and light extinction. All of the Pool 8 values greater than 80 mg/L were from Coon Creek and Root River, and five of the seven Pool 13 observations were main channel sites. This indicates that there may be important differences in TSS makeup between tributaries and the main channel that are affecting light extinction.

The effects of seasonal light penetration on vegetation and fish within the Upper Mississippi River remain poorly understood; however, this report presents river managers with tools to predict light extinction based upon commonly collected water-quality variables, thereby providing opportunities to further investigate these unknown effects. Transparency tube, Secchi depth, and turbidity all showed strong relations with light extinction and can be used to effectively predict light extinction. TSS did not show as strong a relation to light extinction. This report also provides some insight into the effect that VSS and NVSS are having on light penetration in the Upper Mississippi River and its tributaries. We expect the general relations and principals presented in this report to apply to other parts of the UMRS as well as other river systems. Utilizing relations presented in this report in conjunction with biological indicators of light penetration, such as SAV, represents important tools in understanding light dynamics within the UMRS (Sullivan and others, 2009). The light regime on the Upper Mississippi River has wide-ranging ramifications that affect the overall health of the ecosystem, and we have illustrated that readily available data can be used to predict light extinction

Table 10. Comparison of total suspended solids, volatile suspended solids, nonvolatile suspended solids, and percentage volatile suspended solids for Pools 8 and 13.

[N, number of measurements; TSS, total suspended solids; mg/L, milligrams per liter; VSS, volatile suspended solids; NVSS, nonvolatile suspended solids; k, light extinction coefficient (m^{-1}); tributary data included; only values greater than 80 mg/L TSS are included]

	N	TSS (mg/L)	VSS (mg/L)	NVSS (mg/L)	Percentage VSS	k
Pool 8 average	9	107.04	12.34	94.7	11.42	5.05
Pool 13 average	7	102.76	16.51	86.24	16.26	7.97

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Long Term Resource Monitoring Program—**Evaluation of Light Penetration on Navigation Pools 8 and 13 of the Upper Mississippi River**

The Long Term Resource Monitoring Program (LTRMP) for the Upper Mississippi River System was authorized under the Water Resources Development Act of 1986 as an element of the Environmental Management Program. The mission of the LTRMP is to provide river managers with information for maintaining the Upper Mississippi River System as a sustainable large river ecosystem given its multiple-use character. The LTRMP is a cooperative effort by the U.S. Geological Survey, the U.S. Army Corps of Engineers, and the States of Illinois, Iowa, Minnesota, Missouri, and Wisconsin.

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